Singularity

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Ben Zorn

MSR TAB Presentation
June 28, 2004

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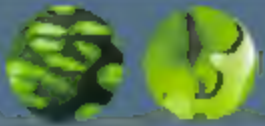
Dependable Artifacts

- Characteristics
  - utility
  - usability
  - predictability
  - reliability
  - cost



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Software is Not Dependable

- For most people, software
  - behaves unpredictably and inexplicably
  - fails often
  - feels insecure, corruptible
  - appears unreliable and shoddy

- Unhappy state of affairs
  - novelty is wearing off
  - day-to-day tool, not new toy

Why Software is Not Dependable

- Good design is difficult
  - no proven, teachable methodology
- Producing error-free code is hard
  - PPRC's focus
- Minor mistakes have major consequences
  - system architecture is not resilient
- Testing is not systematic
  - but no other general alternative to reduce errors
- Culture emphasizes measurable aspects
  - performance
  - features

Improving Software Technology

- Fundamental technologies
  - programming languages
  - programming tools
  - system architecture and programming model (OS/RT)
- Steady, incremental improvement in each field
- Major improvements cross discipline boundaries
  - legacy and narrow focus constrain progress in each area
- Example: correctness tools
  - languages difficult to analyze soundly
  - specifications not part of code
  - programs run in open and porous environments

Singularity

- Could we build better software if we start afresh?
- Can we build systems that are resilient against programmer faults?

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- Could we build better software if we start afresh?
- Can we build systems that are resilient against programmer faults?
- How would software development evolve if dependability was primary goal?
- Can we accelerate progress in software by attacking problems from several directions?
- What technology will MS need to build dependable software?

Singularity Big Bet

- Use managed code throughout to reduce errors and virtualize instruction stream
- Constrain language and programming model to favor verification
- Close execution environment to facilitate compilation and program analysis
- Introduce strong process isolation to minimize consequence of programmer faults
- Make communication explicit and carefully checked

- **Singularity OS (Hunt)**
- Programming Language and Tools (Larus)
- Compiler and Runtime Environment (Zorn)
- Application Domain & Validation
- Conclusion

OS Research Big Bets

- The Singularity razor
  - no unsafe code

OS Research: Big Bets

- The Singularity razor
  - no unsafe code
- Benefits
  - sses for performance

OS Research Big Bets

- The Singularity razor
  - no unsafe code
- Benefits
- Research opportunities

Adding Isolation to Managed Code

- Managed code doesn't provide isolation or fault containment
- Strong process isolation model
  - no shared memory between processes
  - no dynamic code loading, process sealed at creation
- Singularity process
  - isolated object space with threads
  - unit of memory management
  - unit of security policy enforcement
  - unit of system extension
  - target for complete optimization
- Is not
  - address space
  - extensible once started

Singularity
OS Architecture
Trusted
Computing Base
User Programs
Daemons
File Systems
Network Protocols
Device Drivers
Metadata Providers
MSIL Verifier &
Code Generators
Guest
Code
Virtual
Additions
VPC Kernel
Processors and Other Hardware

Strong Isolation for Managed Code

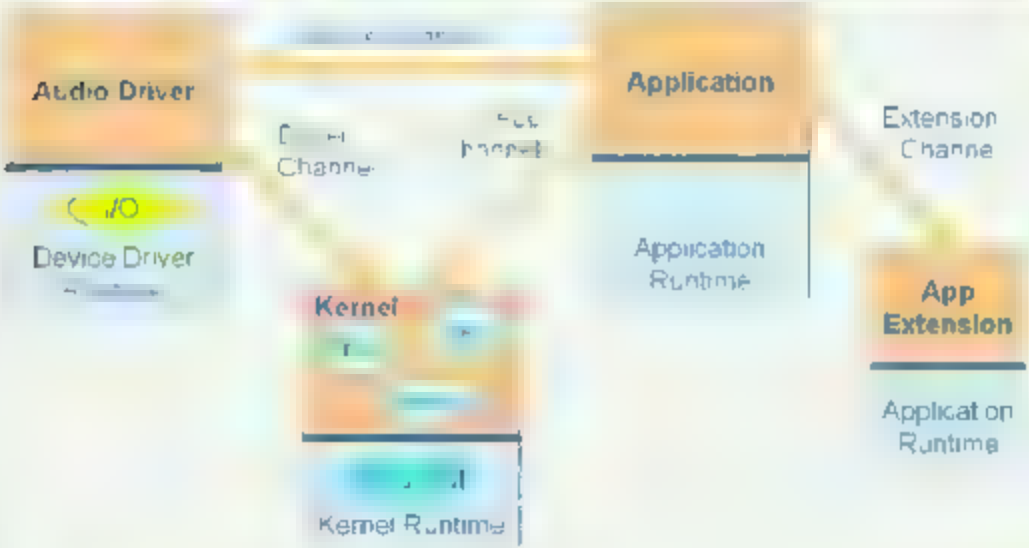
- Managed code doesn't provide isolation or fault containment
- Strong process isolation model
  - no shared memory between processes
  - no dynamic code loading; process sealed at creation
- Singularity process
  - isolated object space with threads
  - unit of failure and termination
  - unit of security policy enforcement
  - unit of system extension
  - target for complete optimization
- Is not
  - address space
  - extensible once started

Singularity OS Architecture

Communication Model

- Explicit communication model
  - all communication through channels typed by contract
  - contract defines types and patterns of messages
- Singularity channel
  - bidirectional asynchronous message transport
  - accessed through exactly two endpoints
  - moved by placing endpoint in a message
- Is not
  - movable except in statically verified state
  - accessible after endpoint has moved

Prozessen


Audio Driver
I/O
Device Driver
Application
Application
Runtime
Extension
Channe
App
Extension
Applicat on
Runtime
Kernel
Kernel Runtime

Administration and Maintenance

- Ubiquitous metadata
  - administration policies described in declarative metadata
  - setup and patching are OS not application responsibility
- Singularity application abstraction
  - first-class OS abstraction describing an application
  - statically described in an application manifest
  - complete description of entire system (including kernel)
  - basis for installation and maintenance
  - dynamically exposed for introspection

Security

- Orthogonal administration of isolated applications
  - application isolation instead of virtual PCs
- Singularity process-based security model
  - fixes identity at creation time [code, user, machine]
  - arbitrates process creation
  - arbitrates channel endpoint propagation
  - supports absolute process content privacy
- Model does not
  - use CLR code access security
  - provide security granularity smaller than process

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Language Standing Points

- Spec#
  - superset of # developed by FSE and SPT groups
  - pre- post conditions & invariants
    - statically verify subset
    - runtime assertions and test case generation
  - while leveraging experimentation
    - evolve language with tools
- Conformance checking
  - behaviorally typed message passing channels
  - ensure client server code obeys channel protocol
  - modular checks lead to global deadlock freedom

Language Research Goals

- Language to support reliable software
  - focus on problematic aspects of programming
  - balance static verification and runtime mechanisms
    - compile-time precision
    - expressiveness late in the life cycle
- Test new features against realistic, but manageable code base
- Basis for Java/C# successor

Language Research Topics

- Error handling
  - lightweight transactions to restore state
  - static checking of explicit restore code
- Concurrency
  - atomic blocks identifies unit of concurrent update
  - enhanced types identify shared data
  - optimistic & pessimistic implementations
- Modularity
  - functions & classes are mechanism for building abstractions
  - need better language mechanisms (modules)

Rotor Starting Point

- Build on research in SPT, FSE, and TVM groups
- Boogie extended static checker for Spec#
  - sound
    - object invariants
    - and other features
- Zing model checker
  - targeted at language verification
  - used for a variety of concurrency related tools
- Test generation tools driven from Spec# annotations
- Managed code tools from PPRC

Language Research Topics

- Error handling
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  - functions & classes are mechanism for building abstractions
  - need better large grain mechanisms (modules)

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Project Related Goals

- Accelerate co-evolution of languages and tools
- Employ tools throughout entire project lifetime
- Scale tools from components (e.g. drivers) to systems
- Identify opportunities for new tools and build them

[illegible]

- Formal design
  - modeling tools for critical aspects of system
  - formal specification, simulation, and verification
- Correctness
  - continue research
- Security & privacy
  - beyond exploits to system level problems
  - information flow
  - runtime monitoring
- Testing
  - static analysis to increase test effectiveness
  - usage profiles

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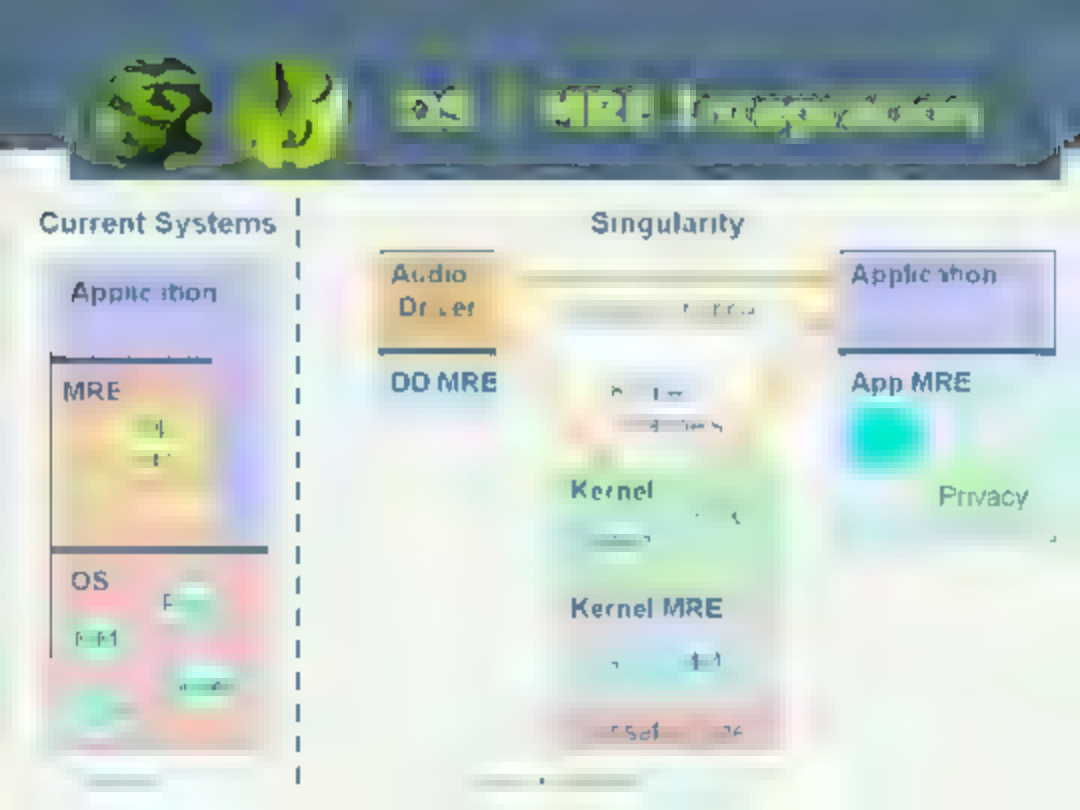
Compiler and Managed Runtime Environment

- Big bets
  - Between JVOS and managed code runtime
  - limits of interfacing benefit performance and correctness
    - e.g., to dynamic code loading
  - real time and kernel garbage collection
- Managed Runtime Environment (MRE)
  - Its architecture neutral instruction set
  - base class library, synchronous I/O, etc
  - services: garbage collection, reflection
- Existing MREs designed for applications, not system


Current Systems
Application
MRE
OS
Singularity
Audio
Driver
DD MRE
Kernel
Kernel MRE
Application
App MRE
Privacy

Research Goals

- Compiler
  - produce high performance managed system
  - integrate types into lowest levels of system
- Runtime
  - make GC suitable for kernel
  - exploit runtime to improve correctness and performance

    rethink runtime services (e.g. reflection)
  - customize MREs for application domains

Compiler Research Topics

- Typed assembly language (TAL)
  - create a TAL suitable for C, C++ languages
  - also suitable for MRE's low-level implementation (JVM)
  - show MRE + application program is strongly type safe
    - e.g. program type safe after running runtime type test
- Optimization
  - whole program like advantage of process scoping
  - cross process (system level) optimization
    - e.g. channel communication
- New language features
  - e.g. transactions

Research Topics

- GC in kernel
  - exploit MM info to increase GC locality
  - integrate GC with scheduling for real-time apps
  - support multiple GCs for diverse app requirements
- Use runtime to enhance correctness
  - GC has global view of heap connectivity
  - sampling can collect arbitrary runtime info
- Rethinking runtime
  - move reflection to compile time (e.g., loading)
  - defining HREs as unit of abstraction

Compilation / MRE Starting Points

- Build on research in ACT and RAD groups
- First compiler / MRE based on Bartok
  - optimizing MSIL to native code compiler
  - lightweight runtime system
  - runtime and compiler written entirely in C#
- Ongoing runtime locality and correctness research
  - hot data streams
  - statistical error detection
    runtime data collection and sampling

Overview

- Singularity OS (Hunt)
- Programming Language and Tools (Larus)
- Compiler and Runtime Environment (Zorn)
- **Application Domain & Validation**
- **Conclusion**

Application Home Server

- Platform for home services
  - [illegible]
  - [illegible]
  - Recast / recover and continue after failure
- Home services
  - [illegible]
  - backup (Mirva
  - home automation
  - [illegible]
- Alternative to single function appliances
  - lower fixed cost
  - better integration
  - lower barrier for in[illegible]n (Wang vs F[illegible]
- Infrastructure to "software as service"
- TAB suggestions are very welcomed (want a device for home?)

Participants

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Status and Milestones

- June 2004:
  - simple Singularity kernel with threads and channels
  - Bartok runtime system on bare metal
  - type safe device drivers and PnP support
  - Spec# compiler generating MSIL
- September 2004
  - Spec# extensions
  - real-time scheduler
  - more device drivers
  - services (name service, file system)
  - processes and more efficient threads and channels
  - application abstraction (metadata)
- December 2004
  - first application deployment to home machines

Conclusion

- Imperative to develop tools and techniques to build dependable software
- Dependability requires major, synergistic changes in languages, tools, and system architecture
- Singularity deliverables:
  1. specification and modeling tools
  2. verifiable programming languages
  3. program correctness tools
  4. real-time managed code system
  5. strong isolation OS
  6. self-descriptive system and applications

Backup Slides